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(54) **INCREMENTAL FILE SYSTEM DIFFERENCING**

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(52) **U.S. Cl.** **707/690**; 707/697

(58) **Field of Classification Search** .... None
See application file for complete search history.

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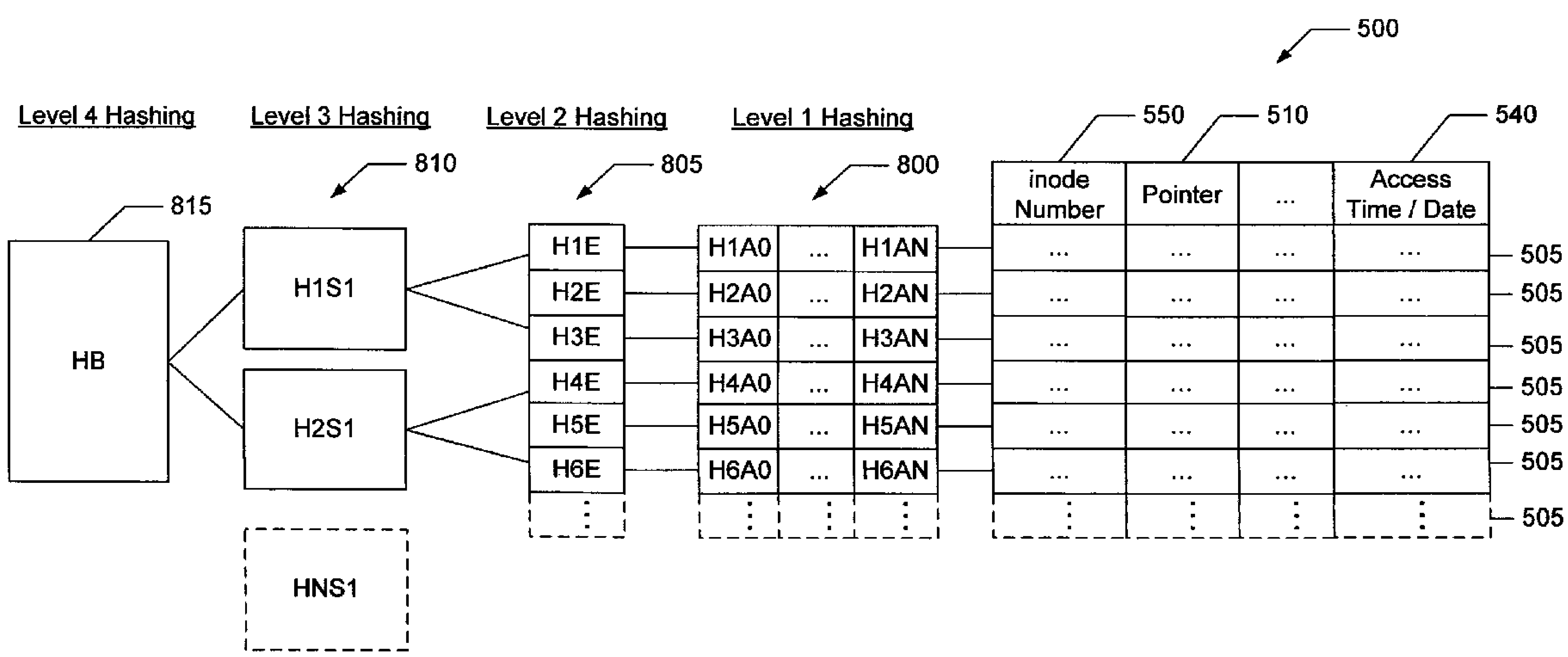
(57) **ABSTRACT**

A facility for comparing two datasets and identifying metadata differences between the two datasets irrespective of the manner in which the data is stored. In some embodiments, the facility includes a comparison unit and a catalog unit. The comparison unit compares a hierarchical hash of a first dataset with a hierarchical hash of a second dataset, the hierarchical hashes each including a plurality of hierarchical hash values, to identify differences in metadata of the first and second datasets by progressively comparing the hierarchical hash values of the first and second hierarchical hashes without comparing the metadata of the first and second datasets. The catalog unit generates a catalog of differences between the first and second datasets, the catalog indicating differences in metadata of the first and second datasets.

17 Claims, 10 Drawing Sheets



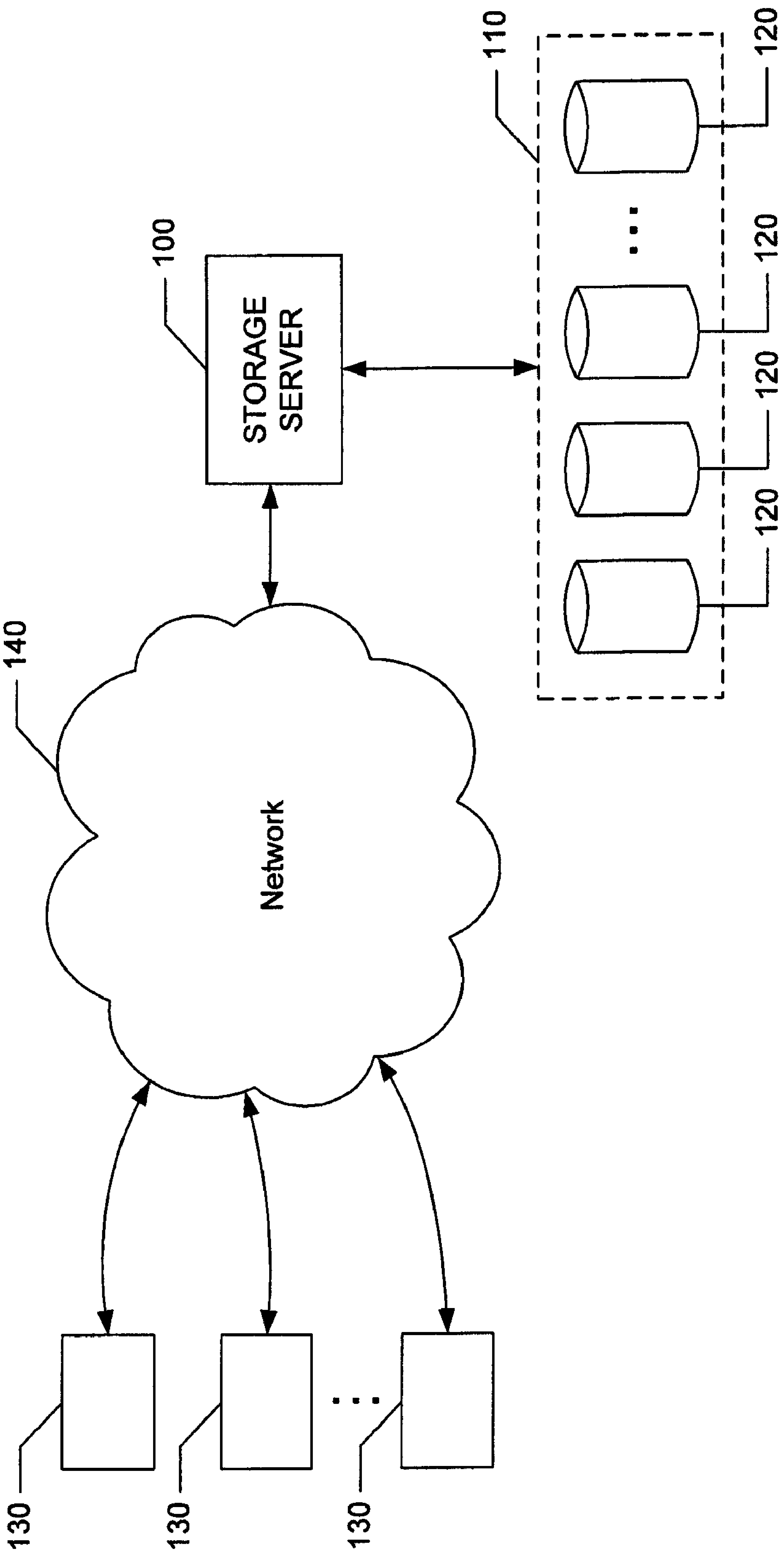

100
STORAGE SERVER
110
120
120
120
120
140
Network
130
130
130

FIG. 1

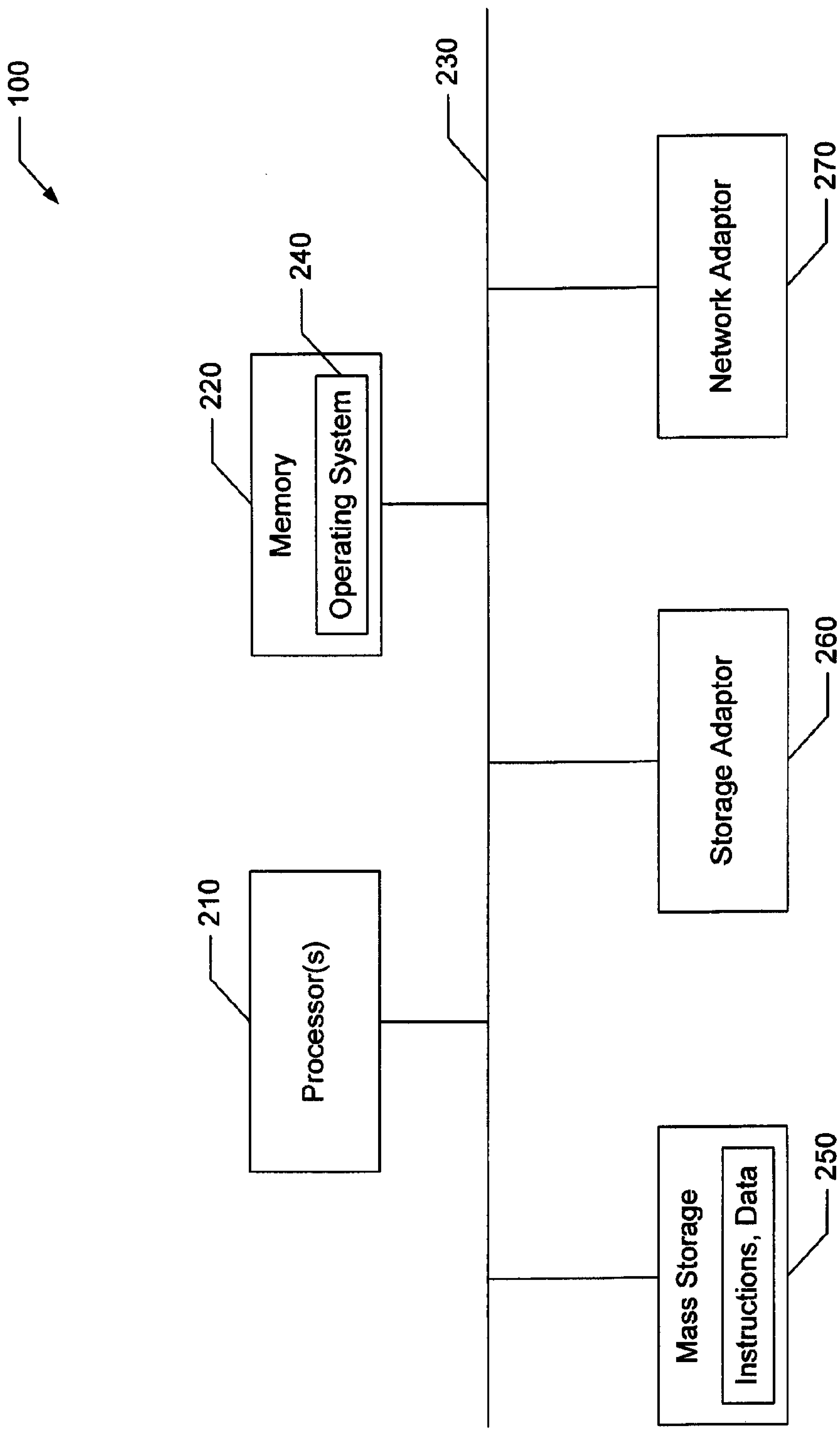

100
230
240
220
Memory
Operating System
270
Network Adaptor
210
Processor(s)
260
Storage Adaptor
250
Mass Storage
Instructions, Data

FIG. 2

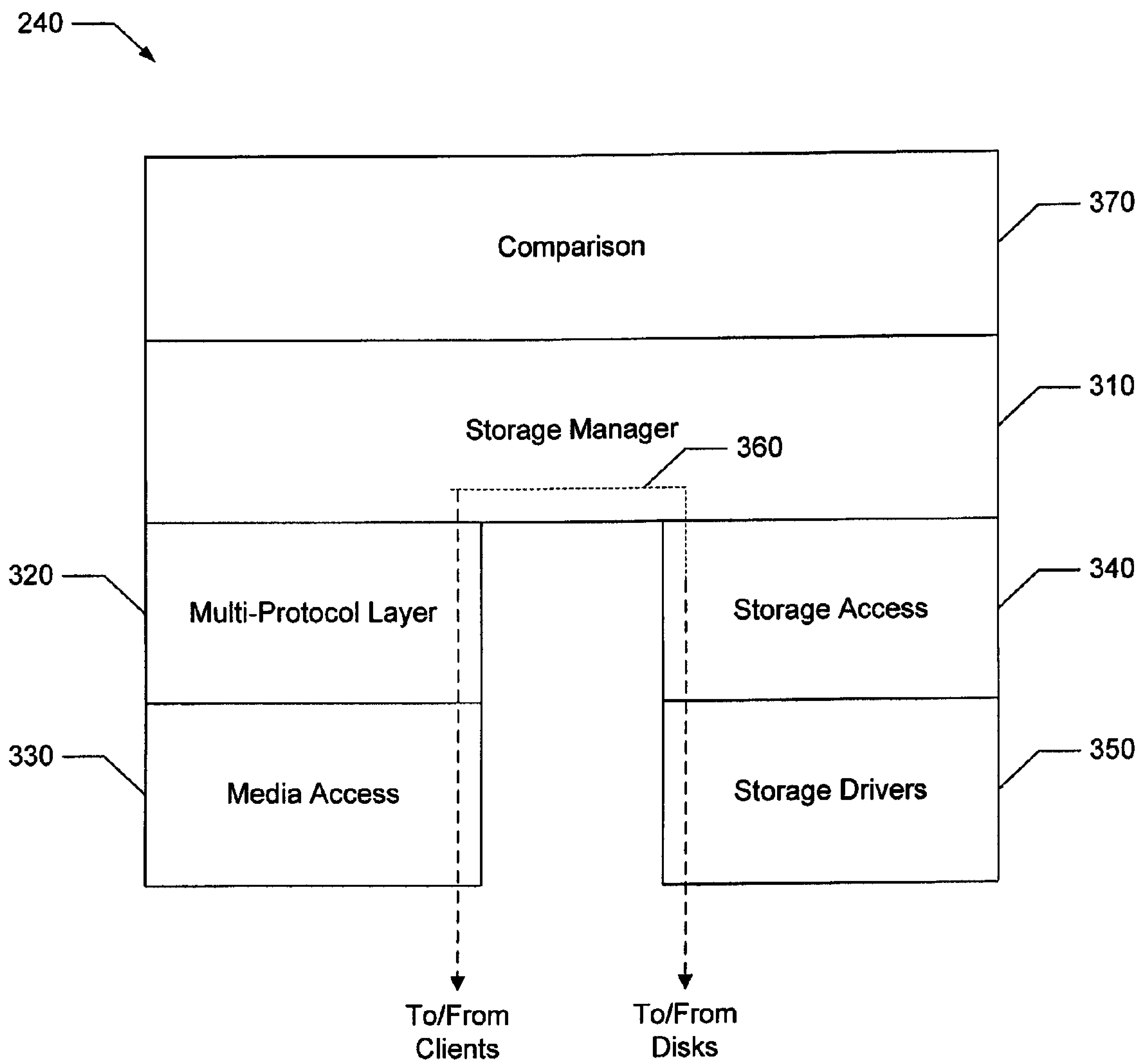

240
Comparison
370
Storage Manager
310
360
Multi-Protocol Layer
320
Storage Access
340
Media Access
330
Storage Drivers
350
To/From Clients
To/From Disks

FIG. 3

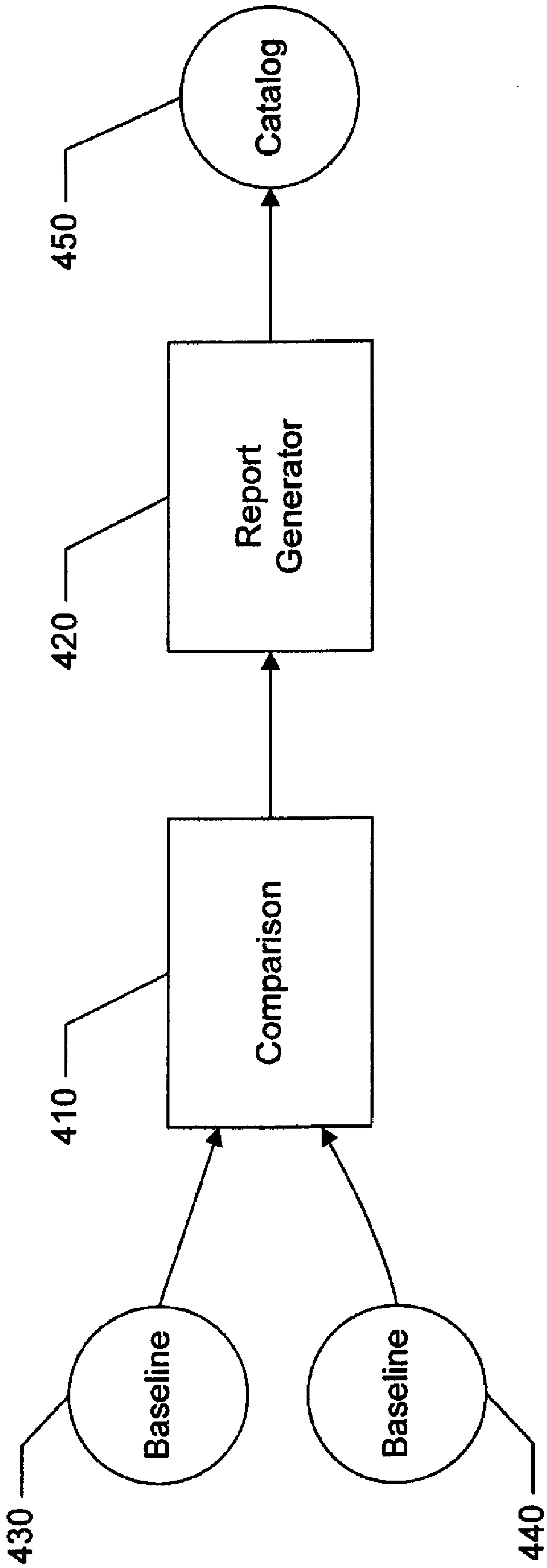

450
Catalog
420
Report Generator
410
Comparison
430
Baseline
440
Baseline

FIG. 4

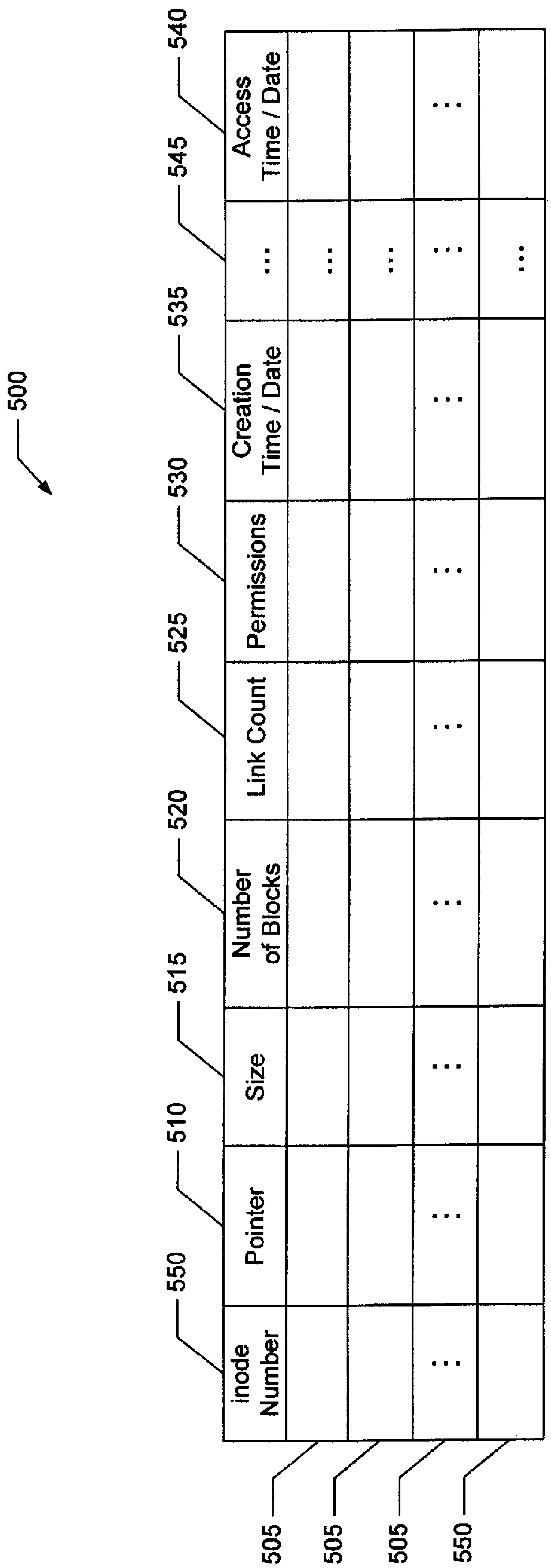

500
540
545
535
530
525
520
515
510
550
Access Time / Date
Creation Time / Date
Permissions
Link Count
Number of Blocks
Size
Pointer
inode Number
505
505
505
550

FIG. 5

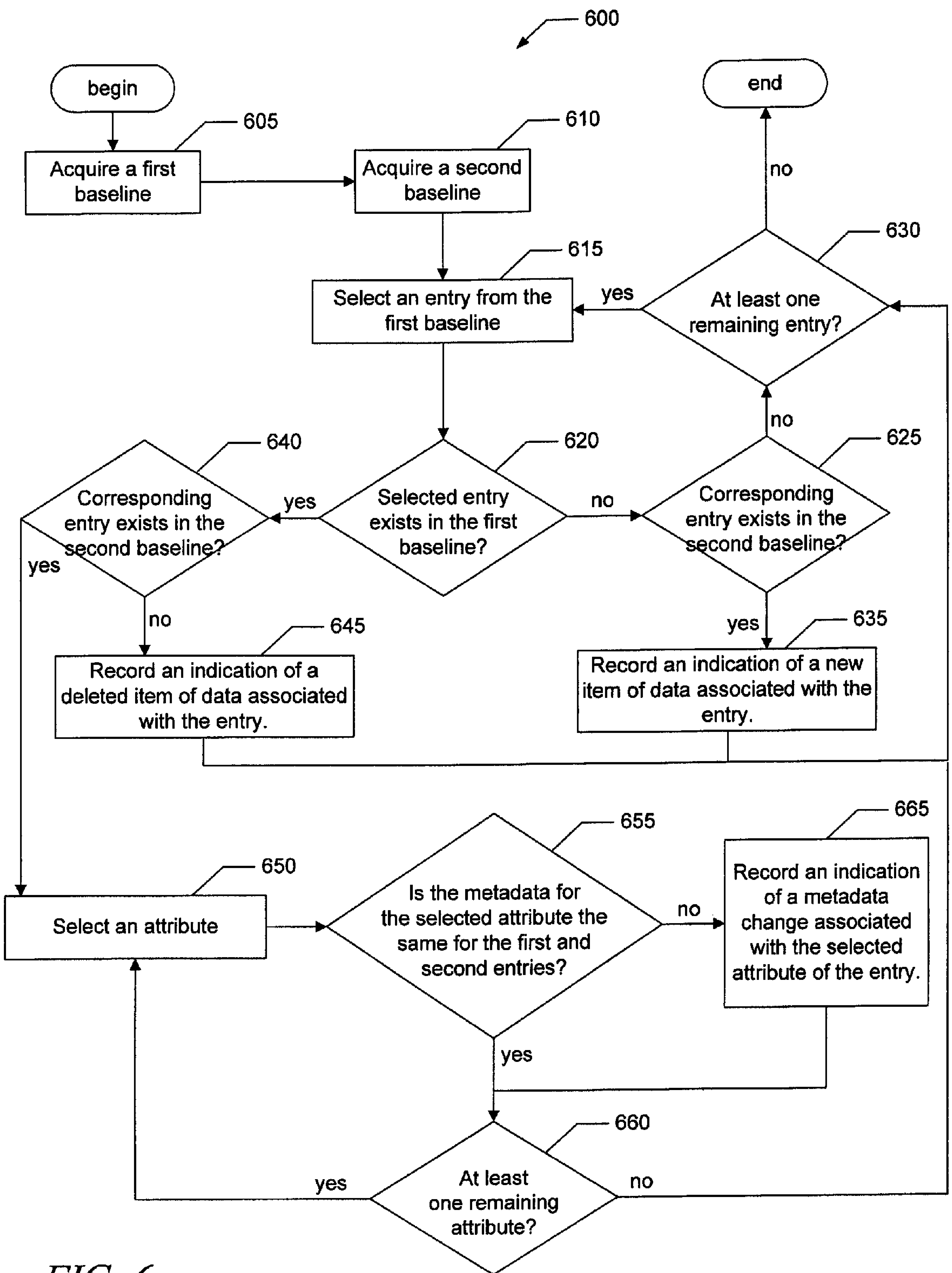

600
begin
605
Acquire a first baseline
610
Acquire a second baseline
end
no
630
At least one remaining entry?
yes
615
Select an entry from the first baseline
no
640
Corresponding entry exists in the second baseline?
yes
620
Selected entry exists in the first baseline?
no
625
Corresponding entry exists in the second baseline?
yes
no
645
Record an indication of a deleted item of data associated with the entry.
yes
635
Record an indication of a new item of data associated with the entry.
655
665
650
Select an attribute
Is the metadata for the selected attribute the same for the first and second entries?
no
Record an indication of a metadata change associated with the selected attribute of the entry.
yes
660
yes
At least one remaining attribute?
no

FIG. 6

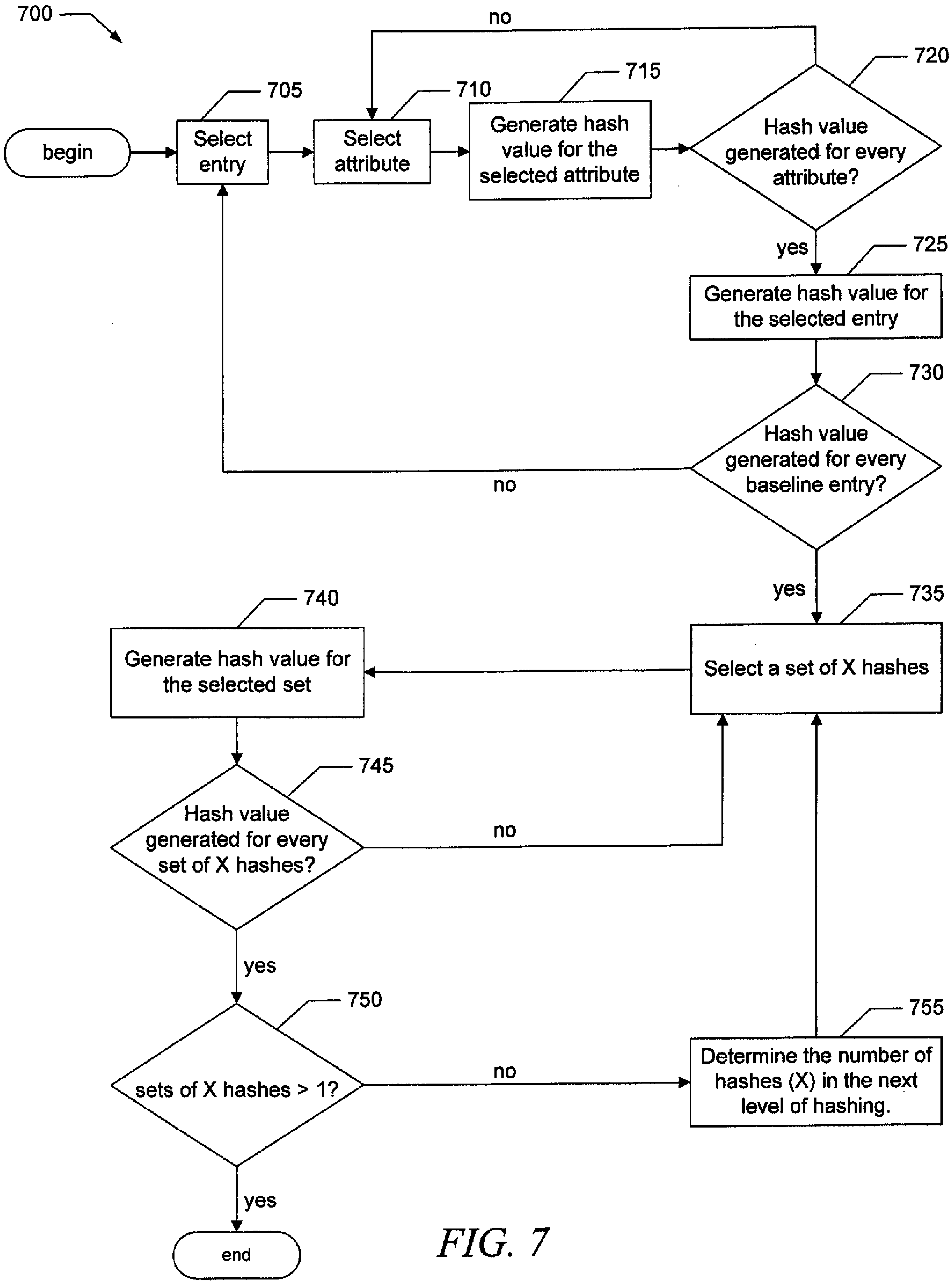

700
begin
Select entry
705
Select attribute
710
Generate hash value for the selected attribute
715
Hash value generated for every attribute?
720
no
yes
Generate hash value for the selected entry
725
Hash value generated for every baseline entry?
730
no
yes
Select a set of X hashes
735
Generate hash value for the selected set
740
Hash value generated for every set of X hashes?
745
no
yes
sets of X hashes > 1?
750
no
yes
Determine the number of hashes (X) in the next level of hashing.
755
end

FIG. 7

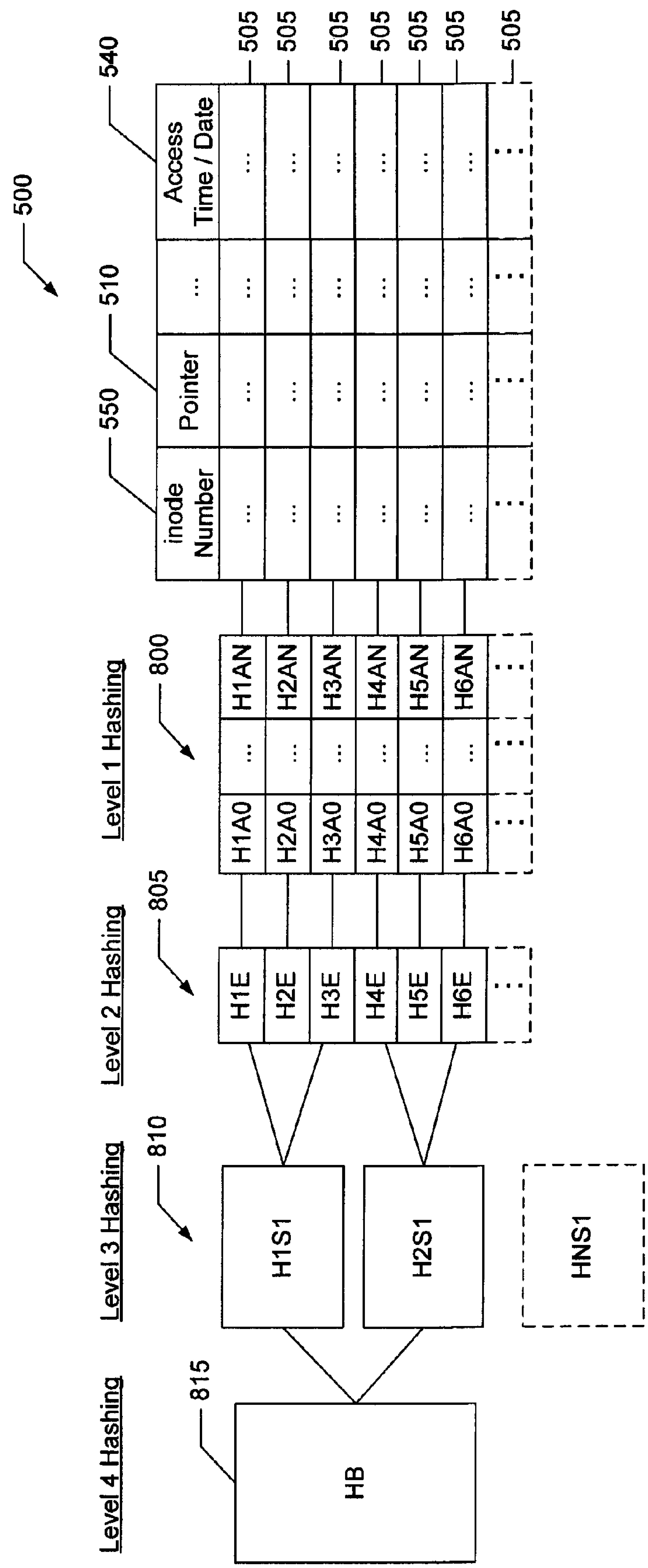
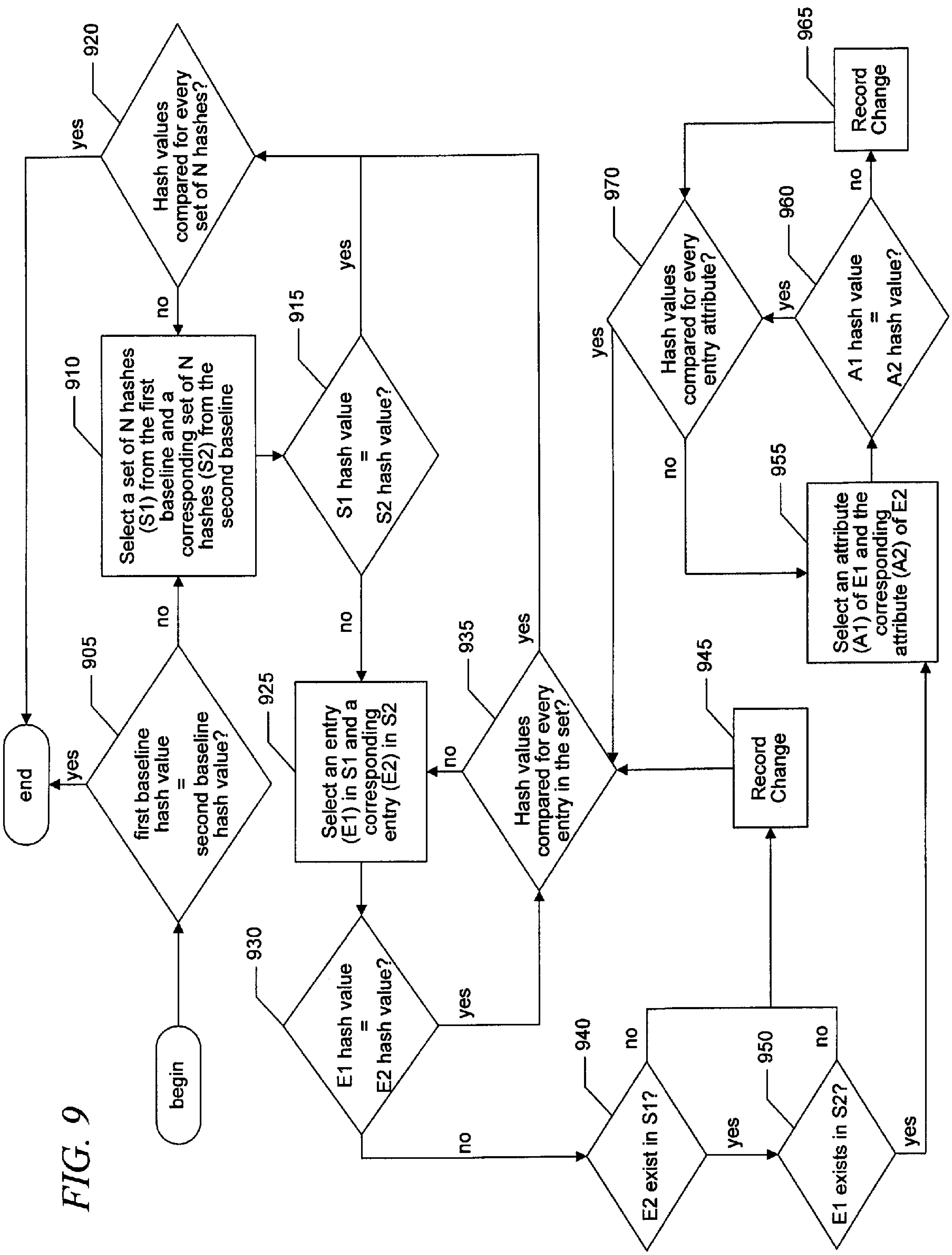

500
550
510
540
inode Number
Pointer
Access Time / Date
505
Level 1 Hashing
800
H1A0
H2A0
H3A0
H4A0
H5A0
H6A0
H1AN
H2AN
H3AN
H4AN
H5AN
H6AN
Level 2 Hashing
805
H1E
H2E
H3E
H4E
H5E
H6E
Level 3 Hashing
810
H1S1
H2S1
HNS1
Level 4 Hashing
815
HB

FIG. 8



begin
905
first baseline hash value = second baseline hash value?
yes
no
end
910
Select a set of N hashes (S1) from the first baseline and a corresponding set of N hashes (S2) from the second baseline
920
Hash values compared for every set of N hashes?
915
S1 hash value = S2 hash value?
925
Select an entry (E1) in S1 and a corresponding entry (E2) in S2
930
E1 hash value = E2 hash value?
935
Hash values compared for every entry in the set?
940
E2 exist in S1?
950
E1 exists in S2?
945
Record Change
955
Select an attribute (A1) of E1 and the corresponding attribute (A2) of E2
960
A1 hash value = A2 hash value?
965
Record Change
970
Hash values compared for every entry attribute?

FIG. 9

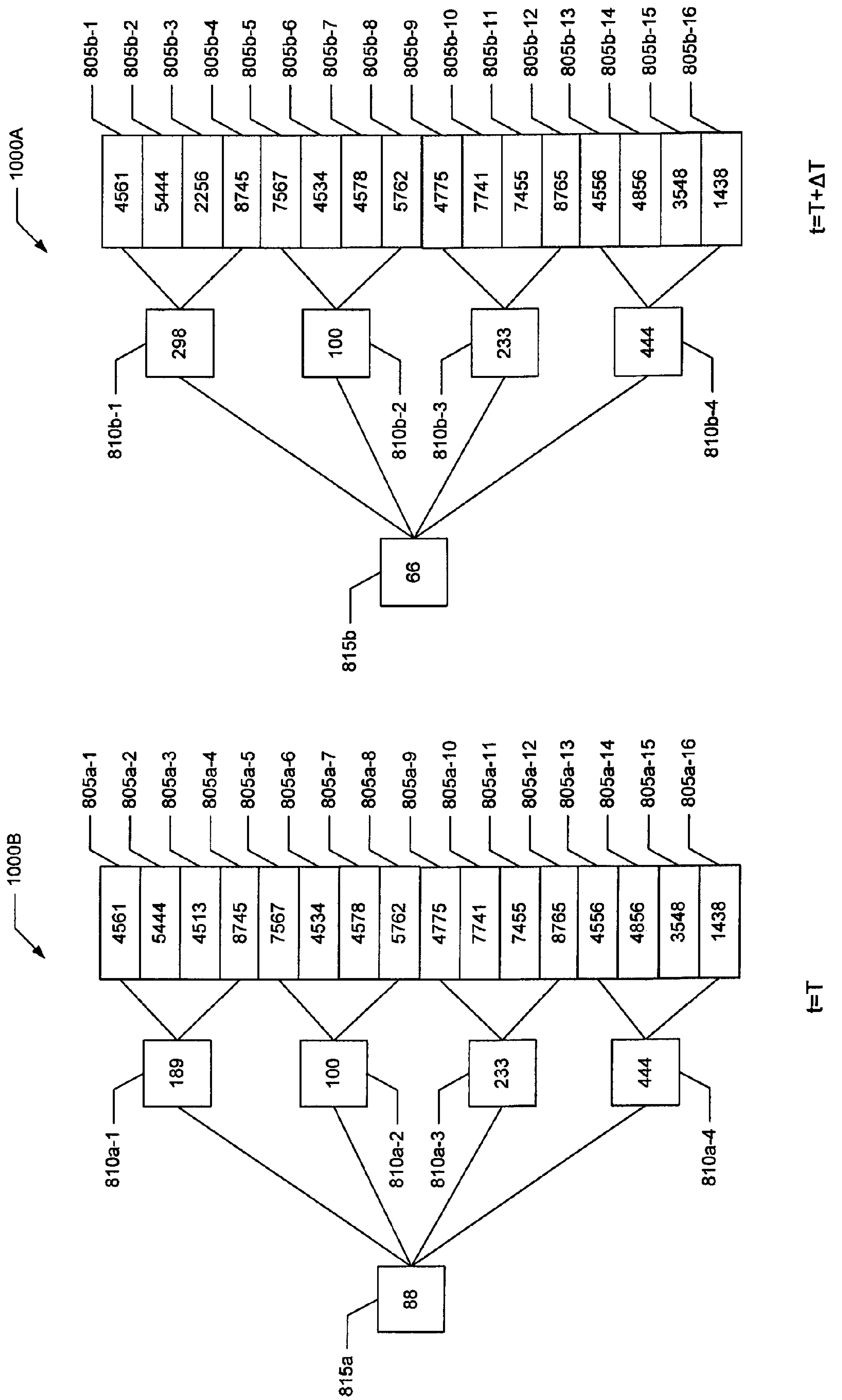

1000A
805b-1
805b-2
805b-3
805b-4
805b-5
805b-6
805b-7
805b-8
805b-9
805b-10
805b-11
805b-12
805b-13
805b-14
805b-15
805b-16
4561
5444
2256
8745
7567
4534
4578
5762
4775
7741
7455
8765
4556
4856
3548
1438
298
100
233
444
810b-1
810b-2
810b-3
810b-4
66
815b
t=T+ΔT
1000B
805a-1
805a-2
805a-3
805a-4
805a-5
805a-6
805a-7
805a-8
805a-9
805a-10
805a-11
805a-12
805a-13
805a-14
805a-15
805a-16
4561
5444
4513
8745
7567
4534
4578
5762
4775
7741
7455
8765
4556
4856
3548
1438
189
100
233
444
810a-1
810a-2
810a-3
810a-4
88
815a
t=T

FIG. 10

INCREMENTAL FILE SYSTEM DIFFERENCING

FIELD OF THE INVENTION

At least one embodiment of the present invention pertains to storage systems, and more particularly, to a method and apparatus to generate information describing the differences between two structured or unstructured datasets.

BACKGROUND

Businesses generate and maintain enormous stores of data. Typically, such data stores are located on one or more network storage devices. For example, data may be stored on a Network Attached Storage (NAS) appliance, a Storage Area Network (SAN), or some combination of these systems. Any one or more multiple types of disk storage (Fibre Channel, SCSI, ATA, and CAS), tape, and optical storage can make up a storage infrastructure. Each storage type offers a different combination of cost, performance, reliability, and content preservation.

For many businesses, data represents a valuable asset that must be managed in a way that enables the business to realize its value. However, the complexity of data storage management has increased significantly due to the rate of growth, value to the business, and the wide variety of data types. Consequently, extracting value from data stores has become more and more dependent on the business's ability to manage metadata (i.e., "data about data")—such as who created a file, when it was last accessed, and so forth. To manage stores of data, businesses necessarily require the ability to describe the differences or changes in metadata describing the stores of data. For example, data backup, Storage Resource Management (SRM), mirroring, and search & indexing are just some of the applications that may need to efficiently discover and describe metadata changes associated with a data store.

Classic backup technologies can describe the changes in a dataset, including renames, deletes, creates, and modification of particular elements. However, their methods for finding the changes between the systems are extremely slow. They "walk" (traverse) the entire file system in a breadth-first or depth-first manner, taking advantage of none of the optimized dataset differencing tools that internal replication tools can utilize. To reduce backup media consumption and system load, backup applications sometimes run differential or incremental backups, in which they attempt to capture only the data that has changed from the previous backup. However, these differential or incremental backups tend not to run significantly faster than the full-system backup, because discovering and describing the changes takes so long.

SRM tools attempt to capture information about the locus of activity on a system. As with backup applications, finding out what parts of the system are active (usually done by determining what is modified) is extremely slow.

Mirrors have difficulty in resolving changes to both sides of a mirror. In mirroring, the data residing between mirrored systems can diverge when both sides of the mirror can be written. Asynchronous mirrors never have a completely current version of the source data. If the source becomes inaccessible and the mirror is brought online for user modification, each half of the mirror will contain unique data. The same can happen to a synchronous mirror, if both sides are erroneously made modifiable. In either case, to resolve the differences between the divergent mirrors will require discovering and describing those differences to the user.

To date, technologists have separated the problems of discovering and describing the changes between two datasets. For example, mirroring applications tend to be extremely efficient at discovering and replicating the changes between versions of a dataset. However, they are incapable of describing those changes at a level that is useful to a human user or another independent application. For example, they can tell a user which blocks of which disks have been changed, but they cannot correlate that information to the actual path and file names (e.g., "My Documents\2003\taxes\Schwab Statements\July"), i.e., "user-level" information.

Another technique, which is described in commonly-owned, co-pending U.S. patent application Ser. No. 10/776,057 of D. Ting et al., filed on Feb. 11, 2004 and entitled, "System and Method for Comparing Data Sets" ("the Ting technique"), can print out the names of files that are different between two datasets. However, the Ting technique does not attempt to describe a potential relationship between those differences. For example, a file may have been renamed from patent.doc to patent_V1.doc. The Ting technique would claim that one dataset had a file named patent.doc and the other has a file named patent_V1.doc; however, it would not look more deeply into the problem and declare that patent.doc had been renamed to patent_V1.doc. Understanding the relationships between the differences is a critical aspect of the overall problem. Moreover, the method of describing the changes in the Ting technique is relatively expensive and slow. The Ting technique was designed with the assumption that the differences will be very few, and that processing effort should therefore be expended in quickly verifying the similarities between the two datasets. This assumption does not often hold true in certain applications.

Another technique, which is described in commonly-owned, co-pending U.S. patent application Ser. No. 11/093,074 of T. Bisson et al., filed on Mar. 28, 2005 and entitled, "Method and Apparatus for Generating and Describing Block-Level Difference Information About Two Snapshots" ("the Bisson Snapshot technique"), can compare two datasets and identify block-level differences between the two datasets, by comparing block-level metadata between the first and second datasets, without comparing the contents of the data blocks of the datasets. The Bisson Snapshot technique, however, was designed with the assumption that the file system implemented by the storage server is known (i.e., file system specific information). This assumption does not necessarily hold true in certain applications.

A file system typically is a structuring of data and metadata on one or more storage devices that permits reading/writing of data on the storage devices (the term "file system" as used herein does not imply that the data must be in the form of "files" per se). Metadata, such as information about a file or other logical data container, is generally stored in a data structure referred to as an "inode," whereas the actual data is stored in data structures referred to as data blocks. The information contained in an inode may include, e.g., ownership of the file, access permissions for the file, size of the file, file type, and references to the locations on disk of the data blocks for the file. The references to the location of the file data blocks are provided as pointers in the inode, which may further reference indirect blocks that, in turn, reference the data blocks, depending upon the quantity of data in the file.

In a write in-place file system, the locations of the data structures, such as inodes and data blocks, on disk are typically fixed and changes to such data structures are made "in-place." In a write-anywhere file system, when a block of data is modified, the data block is stored (written) to a new location on disk to optimize write performance (sometimes referred to as "copy-on-write"). A particular example of a write-anywhere file system is the Write Anywhere File Layout (WAFL®) file system available from NetApp, Inc. of Sunnyvale, Calif. The WAFL® file system is implemented within a microkernel as part of the overall protocol stack of a storage server and associated storage devices, such as disks. This microkernel is supplied as part of Network Appliance's Data ONTAP® software.

The Bisson Snapshot technique uses on-disk information about the file system layout to identify changes between two file system versions. For example, in a write-anywhere file system, anytime the contents of an inode or a direct data block change, all of the pointers which point to that inode or block will also necessarily change. Thus, if two corresponding pointers are found to be identical, then all of the inodes which descend from those pointers must also be identical, such that there is no need to compare any of those inodes. If two corresponding pointers are found not to be identical, the process considers the next level of inodes in the inode tress, skipping any branches of the tree that are identical. However, in a write in-place file system, because changes to data structures are made "in-place," the same process cannot be used to identify changes.

BRIEF DESCRIPTION OF THE DRAWINGS

One or more embodiments of the facility are illustrated by way of example and not limitation in the figures of the accompanying drawings, in which like references indicate similar elements and in which:

FIG. **1** is a data flow diagram of various components or services that are part of a storage network.

FIG. **2** is a high-level block diagram of a storage server.

FIG. **3** is a high-level block diagram showing an example of an operating system of a storage server.

FIG. **4** illustrates the relevant functional elements of a comparison layer, according to some embodiments.

FIG. **5** illustrates an example of a baseline of a volume of structured or unstructured data.

FIG. **6** is a flow chart of a comparison process performed by the facility, in some embodiments.

FIG. **7** is a flow chart of a process performed by the facility to generate a hierarchical hash of a baseline, in some embodiments.

FIG. **8** illustrates an example of a hierarchical hash of a baseline.

FIG. **9** is a flow chart of a comparison process performed by the facility, in some embodiments.

FIG. **10** is an example of two hierarchical hashes of a baseline representing a volume of data at a first and a second point in time.

DETAILED DESCRIPTION

The technology introduced herein includes an efficient way of identifying and characterizing metadata differences or changes between two datasets irrespective of the manner in which the data is stored (including the particular type of file system implemented by a storage server, e.g., write anywhere or write-in-place). It will be appreciated by those skilled in the art that the number of datasets compared to identify changes therebetween may be greater than two.

As used herein, a dataset is a logical container of structured, semi-structured, or unstructured data. For example, a file system is a dataset of abstract data types that are implemented for the storage, organization, manipulation, navigation, access, and retrieval of data. File systems typically define a hierarchical namespace that can be used to generate a list of files maintained by the file system (herein referred to as "a baseline"). In some embodiments, a "baseline" is a point-in-time representation (e.g., image) of a dataset stored on one or more storage devices (e.g., on disk) or in other persistent memory and having a name or other unique identifier that distinguishes it from other baselines generated at other points in time. A baseline may also include other information (metadata) about the dataset at the particular point in time that the baseline was generated, such as file metadata. File metadata may include, for example, a pointer to the tree structure of the file, the size (in kBytes) of the file, the number of blocks in the file, the link count (number of references to that file in the volume), file ownership, permissions associated with the file, access time/date, creation time/date, and so forth.

Baselines may be generated on a sporadic basis, on a periodic basis, when a threshold number of transaction requests (e.g., read, write, etc.) is reached, during periods of low activity, and so forth. To facilitate description, it is assumed that the two datasets are baselines of a file system (or a subset thereof) acquired at different points in time. In addition, the number of baselines retained by the facility is configurable by a user or administrator of the facility. For example, in some embodiments, a number of recent baselines are stored in succession (e.g., a few days worth of baselines each taken at four-hour intervals), and a number of older baselines are retained at increasing time spacings (e.g., a number of daily baselines for the previous week(s) and weekly baselines for the previous few months). However, it is contemplated that a variety of baseline creation techniques and timing schemes can be implemented.

In some embodiments, baselines are compared by progressively comparing corresponding hierarchical hashes of the baselines, to identify differences in individual entries of the baseline, each entry corresponding to an item of data stored in a volume of data (or dataset) represented by the baselines. The comparison does not require moving or copying of either baseline in the process. A human-readable report or catalog of the differences between the datasets is then generated, where the report indicates the metadata differences in individual baseline entries. Note that in this description, the terms "changes" and "differences" and variations of these terms are used interchangeably, to facilitate description.

The technology introduced herein is described as a hardware and/or software facility that includes a comparison unit and a catalog unit. The comparison unit compares hashes of a first dataset with corresponding hashes of a second dataset. In some embodiments, multiple levels of hashing are present. That is, the compared hashes may be generated from a number of hierarchical hash values. The facility identifies differences in metadata of the first and second datasets by progressively comparing the hierarchical hash values of the first and second datasets without comparing the metadata of the first and second datasets. The catalog unit generates a catalog of differences between the first and second datasets, the catalog indicates the differences in metadata of the first and second datasets.

Before considering the facility introduced herein in greater detail, it is useful to consider an environment in which the facility can be implemented. FIG. **1** is a data flow diagram that illustrates various components or services that are part of or interact with the facility. A storage server **100** is connected to a storage subsystem **110** which includes multiple mass storage devices **120**, and to a number of clients **130** through a network **140**, such as the Internet or a local area network (LAN). The storage server **100** may be a file server used in a

NAS mode, a block-based server (such as used in a storage area network (SAN)), or a server that can do both. Each of the clients **130** may be, for example, a personal computer (PC), workstation, server, etc. The storage subsystem **110** is managed by the storage server **100**. The storage server **100** receives and responds to various transaction requests (e.g., read, write, etc.) from the clients **130** directed to data stored or to be stored in the storage subsystem **110**. The mass storage devices **120** in the storage subsystem **110** may be, for example, magnetic disks, optical disks such as CD-ROM or DVD based storage, magneto-optical (MO) storage, or any other type of non-volatile storage devices suitable for storing large quantities of data. The storage devices **120** in storage subsystem **110** can be organized as a Redundant Array of Inexpensive Disks (RAID), in which case the storage server **100** accesses the storage subsystem **110** using one or more well-known RAID protocols.

In some embodiments, the facility introduced herein is implemented in the storage server **100**, or in other devices. For example, the facility can be adapted for use in other types of storage systems that provide clients with access to stored data or processing systems other than storage servers. While various embodiments are described in terms of the environment described above, those skilled in the art will appreciate that the facility may be implemented in a variety of other environments including a single, monolithic computer system, as well as various other combinations of computer systems or similar devices connected in various ways. For example, in some embodiments, the storage server **100** has a distributed architecture, even though it is not illustrated as such in FIG. **1**.

FIG. **2** is a high-level block diagram showing an example of the architecture of the storage server **100**. Certain well-known structures and functions have not been shown or described in detail to avoid obscuring the description. The storage server **100** includes one or more processors **210** and memory **220** coupled to an interconnect system **230**. The interconnect system **230** shown in FIG. **2** is an abstraction that represents any one or more separate physical buses and/or point-to-point connections, connected by appropriate bridges, adapters and/or controllers. The interconnect system **230**, therefore, may include, for example, a system bus, a form of Peripheral Component Interconnect (PCI) bus, a HyperTransport or industry standard architecture (ISA) bus, a small computer system interface (SCSI) bus, a universal serial bus (USB), or an Institute of Electrical and Electronics Engineers (IEEE) standard 1394 bus (sometimes referred to as "Firewire").

The processors **210** are the central processing units (CPUs) of the storage server **100** and, thus, control its overall operation. In some embodiments, the processors **210** accomplish this by executing software stored in memory **220**. A processor **210** may be, or may include, one or more programmable general-purpose or special-purpose microprocessors, digital signal processors (DSPs), programmable controllers, application specific integrated circuits (ASICs), programmable logic devices (PLDs), or the like, or a combination of such devices.

Memory **220** includes the main memory of the storage server **100**. Memory **220** represents any form of random access memory (RAM), read-only memory (ROM), flash memory, or the like, or a combination of such devices. Memory **220** stores (among other things) the storage server's operating system **240**.

Also connected to the processors **210** through the interconnect system **230** are one or more internal mass storage devices **250**, a storage adapter **260** and a network adapter **270**. Internal mass storage devices **250** may be or include any conventional medium for storing large volumes of data in a non-volatile manner, such as one or more magnetic or optical based disks. The storage adapter **260** allows the storage server **100** to access the storage subsystem **110** and may be, for example, a Fibre Channel adapter or a SCSI adapter. The network adapter **270** provides the storage server **100** with the ability to communicate with remote devices, such as the clients **130**, over a network and may be, for example, an Ethernet adapter, a Fibre Channel adapter, or the like.

FIG. **3** shows an example of the architecture of the operating system **240** of the storage server **100**. As shown, the operating system **240** includes several software modules, or "layers." These layers include a storage manager **310**. The storage manager **310** is application-layer software that imposes a structure (hierarchy) on the data stored in the storage subsystem **110** and services transaction requests from clients **130**. In some embodiments, storage manager **310** implements a write in-place file system algorithm, while in other embodiments the storage manager **310** implements a write-anywhere file system. Importantly, the facility introduced herein does not depend on the file system algorithm implemented by the storage manager **310**. Logically "under" the storage manager **310**, the operating system **240** also includes a multi-protocol layer **320** and an associated media access layer **330**, to allow the storage server **100** to communicate over the network **140** (e.g., with clients **130**). The multi-protocol layer **320** implements various higher-level network protocols, such as Network File System (NFS), Common Internet File System (CIFS), Hypertext Transfer Protocol (HTTP) and/or Transmission Control Protocol/Internet Protocol (TCP/IP). The media access layer **330** includes one or more drivers which implement one or more lower-level protocols to communicate over the network, such as Ethernet, Fibre Channel or Internet small computer system interface (iSCSI).

Also logically under the storage manager **310**, the operating system **240** includes a storage access layer **340** and an associated storage driver layer **350**, to allow the storage server **100** to communicate with the storage subsystem **110**. The storage access layer **340** implements a higher-level disk storage protocol, such as RAID, while the storage driver layer **350** implements a lower-level storage device access protocol, such as Fibre Channel Protocol (FCP) or small computer system interface (SCSI). Also shown in FIG. **3** is the path **360** of data flow, through the operating system **240**, associated with a transaction request.

In one embodiment, the operating system **240** also includes a comparison layer **370** logically on top of the storage manager **310**. The comparison layer **370** is an application layer that generates difference information describing the differences between two or more baselines. In yet another embodiment, the comparison layer **370** is included in the storage manager **310**. Note, however, that the comparison layer **370** does not have to be implemented by the storage server **100**. For example, in some embodiments, the comparison layer **370** is implemented in a separate system to which baselines are provided as input.

To facilitate description, it is assumed that the storage server **100** is capable of generating or acquiring baselines, at different points in time, of all of the data which it stores (e.g., files and directories), or specified subsets of such data. However, the facility may be used to compare and characterize the differences between datasets other than baselines or different versions of a given dataset.

FIG. **4** illustrates the relevant functional elements of the comparison layer **370** of the operating system **240**, according to one embodiment. The comparison layer **370** (shown in

FIG. **4**) includes a comparison unit **410** and a report generator **420**. The comparison unit **410** receives as input two or more baselines **430** and **440** of a volume of data maintained by the storage server **100**, acquired at two different points in time. The comparison unit **410** processes the baselines **430** and **440** to identify the differences therebetween. The report generator **420** processes generates a catalog of the differences identified by the comparison unit, including the locations associated with any changed items of data and the specific metadata changes. The catalog generated by the report generator **420** is in a human-readable form.

In some embodiments, the comparison unit **410** and report generator **420** are embodied as software modules within the comparison layer **370** of the operating system **240**. In other embodiments, however, the functionality provided by these units can be implemented, at least in part, by one or more dedicated hardware circuits. The comparison unit **410** and report generator **420** may be stored or distributed on, for example, computer-readable media, including magnetically or optically readable computer discs, hard-wired or preprogrammed chips (e.g., EEPROM semiconductor chips), nanotechnology memory, or other data storage media. Indeed, computer implemented instructions, data structures, screen displays, and other data under aspects of the invention may be distributed over the Internet or over other networks (including wireless networks), on a propagated signal on a propagation medium (e.g., an electromagnetic wave(s), etc.) over a period of time, or they may be provided on any analog or digital network (packet switched, circuit switched, or other scheme).

FIG. **5** illustrates an example of the structure of a baseline **500**, according to certain embodiments. A baseline may correspond to a specified set or subset of the data (e.g., a "volume" of data) maintained by the storage server **100**. A volume may include items of data stored on one or more physical storage devices (e.g., storage devices **120**). Note that an actual baseline of a volume of data is likely to be considerably more complex than baseline **500**. Also, for simplicity, the underlying items of data and associated metadata are not shown.

Baseline **500** includes one or more entries **505**, each representing an item of data, such as a file or directory. Each baseline entry **505** is divided into a number of metadata fields (sometimes referred to as "attributes") describing the item of data. For example, the metadata fields may include a pointer field **510**, a size field **515**, a number of blocks field **520**, a link count field **525** (i.e., number of references to that item of data in the volume), a permissions field **530**, a creation time/date field **535**, and an access time/date field **540**. Baseline entries **505** may include other metadata fields **545** not mentioned here.

As described here, the metadata associated with an item of data, such as information about a file, is typically stored in a unit of storage called an "inode," and the data structures used to contain the actual data are called data blocks. The information contained in an inode may include, e.g., ownership of the file, access permissions for the file, size of the file, file type, and references to the locations on disk of the data blocks for the file. The references to the location of the actual data are provided as pointers in the inode, which may further reference indirect blocks that, in turn, reference the data blocks, depending upon the quantity of data in the file. Each item of data in a volume has a separate inode which contains the item's metadata. Each baseline entry **505** is uniquely identified by the item's inode number (contained in inode number field **550**) or other type of unique identifier field.

In some embodiments, the baseline includes an entry for every possible inode number. For example, if each inode number is 32 bits in length, a baseline will include approximately 4 billion entries (2^{32}), some of which will be empty. The number of empty entries is equal to approximately 4 billion minus the number of used entries. In some embodiments, the facility implements a baseline as a sparse file. A feature of a sparse file is that space is only allocated for meaningful (nonzero) data. That is, when space has been allocated to a sparse file, but not actually filled with data, it is not written to the file system. Instead, brief information about these empty regions is stored, which takes up much less disk space. These regions are only written to disk at their actual size when data is written to them.

As described herein, the facility introduced herein is independent of the file systems (write in-place or write-anywhere) that produced the data being compared and provides quick and efficient approach to identify changes between two datasets, such as two baselines representing a volume of data. For example, in some embodiments, the facility evaluates two baselines generated from the same volume of data at different points in time—an earlier-in-time baseline and a later-in-time baseline—and determines when an item of data has been added, deleted, or modified.

Typically, when an item of data is modified, added, or deleted, at least some of the metadata in that item's inode will change. By comparing corresponding entries of a first baseline **430** and a second baseline **440**, the facility generates an incremental change list indicating the changes between the items of data represented by the first and second baselines. FIG. **6** is a flow chart of a process **600** performed by the facility in some embodiments to identify such changes. To facilitate description, the baseline which forms the basis of the comparison in the following process shall be referred to as the "first baseline" (**430**) and the other baseline shall be referred to as the "second baseline" (**440**). Note, however, that the "first baseline" is not necessarily the earlier baseline; the later baseline can be the "first baseline" and the earlier baseline can be the "second baseline."

Initially, at **605** the facility acquires a first baseline **430** of a volume of data. Next, at **610**, the facility acquires a second baseline **440** of the volume of data. To facilitate description, it is assumed that the first and second baselines represent the same volume of data at different points in time. Further, those skilled in the art will understand that the facility may or may not generate one or both of the baselines. For example, in some embodiments, the first and second baselines are provided to the facility as input from another system.

After the first and second baselines are acquired, the facility proceeds to **615** where an entry **505** is selected from the first baseline **430**. Next, at **620**, the facility determines whether the selected entry exists in the first baseline (this may be accomplished, for example, by the comparison unit **410**). That is, whether the selected entry is associated with an item of data. If the selected entry does exist in the first baseline, the facility proceeds to **640**. If the selected entry does not exist in the first baseline, the facility proceeds to **625**.

At **625**, the facility determines whether a corresponding entry **505** exits in the second baseline **440** (this may be accomplished, for example, by the comparison unit **410**). If a corresponding entry does not exist in the second baseline, this means that there was not (at the time the first baseline **430** was generated) and is not (at the time the second baseline **440** was generated) an item of data associated with the entry **505**. In that case, the facility proceeds to **630** to determine whether there is at least one remaining entry **505** of the first baseline **430** to process. Otherwise, if at **625** the facility determines that a corresponding entry does exist in the second baseline, this means that the item of data associated with the entry **505** was created after the first baseline **430** was generated. In that case, the facility proceeds to **635** where an indication of a new item of data associated with the entry **505** is recorded (this may be accomplished, for example, by the report generator **420**). After **635**, the facility continues processing at **630**, as described below.

At **640**, the facility determines whether a corresponding entry **505** exists in the second baseline **440** (this may be accomplished, for example, by the comparison unit **410**). If a corresponding entry does not exist in the second baseline, this means that item of data associated with the entry **505** was deleted after the first baseline **430** was generated. In that case, the facility proceeds to **645** where an indication of a deleted item of data associated with the entry **505** is recorded (this may be accomplished, for example, by the report generator **420**). After **645**, the facility continues processing at **630**, as described below. Otherwise, if at **640** the facility determines that a corresponding entry does exist, this means that there was (at the time the first baseline **430** was generated) and is (at the time the second baseline **440** was generated) an item of data associated with the entry **505**. In that case, the facility proceeds to **650**.

At **650**, the facility selects an attribute (e.g., **510**) for comparison. Next, at **655**, the facility determines whether the metadata for the selected attribute is the same for the selected first entry and corresponding second entry (this may be accomplished, for example, by the comparison unit **410**). If the metadata for the selected attribute is the same, this means that the item of data has not changed with respect to the selected attribute, and the facility continues processing at **660**, as described below. Otherwise, if the metadata for the selected attribute is not the same, this means that the item of data has changed. In that case, the facility proceeds to **665** where an indication of a metadata change associated with the entry **505** is recorded (this may be accomplished, for example, by the report generator **420**). After **665**, the facility continues processing at **660**.

At **660**, the facility determines whether there is at least one remaining attribute (e.g., **515**) to process for the entry **505**. If there is at least one remaining attribute, the facility continues processing at **650**, as described above. Otherwise, the facility continues processing at **630**. At **630**, the facility determines whether there is at least one remaining entry **505** of the first baseline **430** to process. If there is at least one remaining entry, the facility continues processing at **615**, as described above. Otherwise the facility ends processing.

Those skilled in the art will appreciate that the blocks shown in FIG. **6** and in each of the following flow diagrams may be altered in a variety of ways. For example, the order of certain blocks may be rearranged; certain substeps may be performed in parallel; certain shown blocks may be omitted; or other blocks may be included; etc.

In some embodiments, to reduce the amount of time and/or space necessary to compare two or more baselines, the facility generates a hierarchical hash of each baseline. FIG. **8** illustrates an example of a hierarchical hash of a baseline. FIG. **7** is a flow chart of a process **700** performed by the facility to generate a hierarchical hash of a baseline. Process **700** may be performed while a baseline is generated or after the baseline is generated. Process **700** may be triggered by a user command or it may be triggered automatically, such as at predetermined times or intervals or in response to a specified event.

At **705**, the facility selects an entry **505** of a baseline. Next, at **710**, the facility selects an attribute (e.g., **510**) of the selected entry. At **715**, the facility generates a hash value **800** associated with the selected attribute. Those skilled in the art will understand that a hash value can be generated using a variety of hash functions—such as SHA1, SHA256, SHA384, SHA512, Tiger, elf64, HAVAL, MD2, MD4, MD5, RIPEMD-64, RIPEMD-160, RIPEMD-320, WHIRLPOOL. A hash function is any well-defined procedure or algorithm for transforming some kind of data into a unique, relatively small value (sometimes referred to as a hash value, hash code, hash sum, or simply a hash). After **715**, the facility proceeds to **720**.

At **720**, the facility determines whether a hash value **800** has been generated for every attribute (e.g., **510**-**545**) of the selected entry. If a hash value **800** has not been generated for every attribute of the selected entry, the facility continues processing at **710**, as described above. Otherwise, the facility proceeds to **725**. At **725**, the facility generates a hash value **805** for the selected entry. The hash value **805** for the selected entry may be generated, for example, by hashing the hash values **800** of the attributes of the selected entry. After **725**, the facility proceeds to **730**.

At **730** the facility determines whether a hash value **805** has been generated for every entry **505** of the baseline. If a hash value **805** has not been generated for every entry **505**, the facility continues processing at **705**, as described above, where the next entry of the baseline is selected. Otherwise, if a hash value **805** has been generated for every entry **505**, the facility proceeds to **735**.

At **735**, the facility selects a set of X hashes **805**. To facilitate description, it is assumed that the set of hashes **805** are each associated with an entry **505** of a set of X entries. However, those skilled in the art will appreciated that the set of X hashes **805** may correspond to hash values that are each associated with a set of entries. Therefore, the level of hashing performed by the facility is reflected by the number of sets of sets of hashes. Next, at **740**, the facility generates a hash value **810** for the selected set by hashing the hash values **805** of the set. Then the facility proceeds to **745** to determine whether a hash value **810** has been generated for every set of X hashes **805**. If a hash value **810** has not been generated for every set, the facility continues processing at **735**, as described above. Otherwise, the facility proceeds to **750**.

At **750**, the facility determines whether there is more than one set of X hashes; that is, whether a single hash value **815** has been generated for the baseline. If a single hash value **815** has been generated, the facility ends processing. Otherwise, the facility proceeds to **755** to determine the number of hashes (X) in the next level of hashing. Then the facility continues processing at **735**, as described above. In other words, the facility recursively loops through **735**-**755** until a single hash value **815** is generated for the baseline.

FIG. **8** is an example of a hierarchical hash of a baseline generated by process **700**. Again, note that an actual baseline of a volume of data is likely to be considerably more complex than the baseline shown in FIG. **8**, although the general approach described herein would still apply. For simplicity, the underlying items of data and associated metadata are not shown.

As described herein, the facility generates hash values **800** for each attribute **510**-**545** of each entry **505**. Then, the facility generates a hash value **805** for each entry **505**, by hashing the hash values **800** of the attributes of each entry. After generating a hash value **805** for each entry, the facility generates a hash value **810** for every set of X hashes **805**, by hashing a set of hash values **805**. As described herein, in some embodiments, the facility performs multiple levels of hashing. FIG. **8** illustrates four levels of hashing. The first level includes hashes **800** associated with attributes of a corresponding entry. The second level includes hashes **805** associated with entries. The third level includes hashes **810** of sets of hashes

805 associated with entries **505** of a baseline. The fourth level includes a hash **815** of sets of hashes **810** associated with sets of sets of entries **505** of the baseline. In some embodiments, a user or administrator establishes the level or hashing performed by the facility, while in other embodiments the facility automatically determines an efficient level of hashing. This may be determined, for example, by monitoring the transaction requests received, by taking into account prior levels of hashing for a particular interval of time (historical trends), the number of entries associated with items of data (meaningful data), etc. Those skilled in the art will appreciated that, under certain conditions, the facility may determine that a different level of hashing than that shown in FIG. **8** is appropriate.

The facility recursively hashes the generated hash values **805**, **810**, etc. until a single hash value **815** is generated for the baseline. By comparing a hash **815** of a baseline **430** representing a volume of data at a first point in time with a hash **815** of another baseline **440** representing the same volume of data at a second point in time, it is possible to determine whether the volume of data has changed between the first and second points in time. If the hash values **815** are identical, the volume of data has not changed. If the hash values **815** are different, the volume of data has changed (i.e., at least one item of data has been added, deleted, or modified).

FIG. **9** is a flow chart of a process **900** performed by the facility to identify changes in one or more items of data represented by a baseline, in some embodiments. As illustrated, the facility progressively compares corresponding hashes for each level of hashing until it determines whether one or more items of data have changed. Note that the facility does not necessarily compare every corresponding hash for each level; instead, the facility compares corresponding hashes within a set of hashes only when the hashes compared at the preceding level (i.e., hashes generated from the set of hashes) are not identical. The facility generates an incremental change list describing the changes associated with items of data at the first and second points in time.

Initially, at **905** the facility compares a hash value **815** of a first baseline **430** with a hash value **815** of a second baseline **440**. If the hash values are the same, this means that there is no difference between the volume of data at the first and second points in time, and the process ends. Otherwise, if the hash values are different, this means that there is at least one change in the volume of data between the first and second points in time, and the facility proceeds to **910**.

At **910**, the facility selects a set of N hashes associated with the first baseline **430** and a corresponding set of N hashes associated with the second baseline **440**. Next, at **915**, the facility compares the hash values (e.g., **810**) of the sets of hashes to determine whether the dataset represented by the selected set of N hashes associated with the first baseline **430** is different from the dataset represented by the corresponding set of N hashes associated with the second baseline **440**. If, at **915**, the hash values are not the same, this means that there is at least change in the volume of data corresponding to the datasets represented by the sets of N hashes, and the facility proceeds to **925**, as described below. Those skilled in the art will appreciate that, in some embodiments, the facility continues processing a subset of the selected set of N hashes (at **915**) until the subset of N hashes correspond to hashes **805** of entries. To facilitate description, however, it is assumed that baselines **430** and **440** have four levels of hashing (as shown in FIG. **8**). If at **915** the hash values are the same, the facility proceeds to **920** to determine whether the process has compared a hash value (e.g., **810**) for every set of N hashes of the first baseline with a hash value (e.g., **810**) of the corresponding set of N hashes of the second baseline. When the facility has compared a hash value for every corresponding set of N hashes, the process ends. Otherwise, the facility continues, processing at **910**, as described above.

At **925**, the facility selects an entry **505** from the selected set and a corresponding entry **505** from the corresponding set. Next, at **930**, the facility compares a hash value **805** of the selected entry **505** with a hash value **805** of the corresponding entry **505**. If the hash values **805** are not the same, this means that the item of data represented by the selected and corresponding entries **505** are different, and the facility proceeds to **940**, as described below. Otherwise, if the hash values are the same, this means that the items of data represented by the selected and corresponding entries **505** are the same (i.e., no change), and the facility proceeds to **935** to determine whether a hash value **805** of every entry **505** of the selected set has been compared with a hash value **805** of a corresponding entry **505** of the corresponding set. If every entry **505** has not been compared, the facility continues processing at **925**, as described above. Otherwise, the facility continues processing at **920**, as described above.

At **940**, the facility determines whether the corresponding entry **505** exists in the first baseline **430**. If the corresponding entry **505** does not exist, this means that the item of data represented by the corresponding entry **505** was added after the first baseline **430** was generated, and the facility proceeds to **945** to record an indication of this change. Otherwise, if the corresponding entry **505** does exist in the first baseline **430**, the facility proceeds to **950**.

At **950**, the facility determines whether the selected entry **505** exists in the second baseline **440**. If the selected entry **505** does not exist, this means that the item of data represented by the selected entry **505** was deleted before the second baseline **440** was generated, and the facility continues processing at **945** to record an indication of this change. After **945**, the facility continues processing at **935**, as described above. However, if at **950** the facility determines that the selected entry **505** does exist in the second baseline **440**, the facility proceeds to **955**.

At **955**, the facility selects an attribute from the selected entry **505** and a corresponding attribute from the corresponding entry **505**. Next, at **960**, the facility compares a hash value **800** of the selected attribute with a hash value **800** of the corresponding attribute. If the hash values **800** are the same, the facility proceeds to **970**, as described below. Otherwise, if the hash values are not the same, the facility proceeds to **965** to record an indication of the change. After **965**, the facility proceeds to **970** to determine whether a hash value **800** for every attribute of the selected entry **505** has been compared with a hash value **800** of a corresponding attribute of the corresponding entry **505**. At **970**, if every hash **800** of the selected entry **505** has not been compared, the facility continues processing at **955**, as described above. Otherwise, the facility continues processing at **935**, as described above.

By progressively comparing hashes **815**, . . . , **810**, **805** and **800** of every fixed set of hashes, it is possible to quickly identify and eliminate datasets of the volume of data which have not changed, and therefore, to quickly identify the items of data that have changed. More specifically, if any two corresponding hashes **815**, **810**, **805** are found to be identical between two baselines, then all of the hashes from which the hash was generated (and any hashes from which those hashes were generated) must also be identical, such that there is no need to compare any of those intervening hashes. If two corresponding hashes **815**, **810**, **805** are found not to be identical, the facility processes the next hashing level, skipping any hashes that are identical, until the changed entries **505** are identified. This approach allows modified (or added or deleted) items of data to be identified without having to examine the actual metadata of those items.

Refer now to FIG. **10**, which shows an example of a hierarchical hash **1000**A of an earlier-in-time baseline **430** and a hierarchical hash **1000**B of a later-in-time baseline **440**. To facilitate description, it is assumed that hierarchical hash **1000**A was generated at a time t=T, while hierarchical hash **1000**B was generated at a time t=T+DELTA_T. For simplicity, the underlying baseline entries are not shown; only the hashes **805** associated with the entries are shown.

Hierarchical hashes **1000**A and **1000**B each include four levels of hashing: (1) a hash **800** per attribute per entry (not shown); (2) a hash **805** per entry; (3) a hash **810** per set of X hashes **805**; and (4) a hash **815** per set of X hashes **810**. Because the value of hash **815***a* is 88 and the value of hash **815***b* is 66, there is at least one difference in the volume of data, and the next hashing level is therefore evaluated. In some embodiments, the facility evaluates the hashes of a hashing level in parallel, while in other embodiments the hashes are evaluated sequentially. As illustrated in FIG. **10**, hashes **810***a*-**2**, **810***a*-**3**, and **810***a*-**4** are identical to corresponding hashes **810***b*-**2**, **810***b*-**3**, and **810***b*-**4**. As described above, because the corresponding hashes are identical there are no differences in the underlying items of data, and the facility does not review the next (or any subsequent) hashing level associated with these hashes. However, because the value of hash **810***a*-**1** is 189 and the value of hash **810***b*-**1** is 298, there is at least one difference in an item of data represented by hash **810***a*-**1** and hash **810***b*-**1**, and the facility will therefore evaluate the next hashing level. That is, the facility compares hashes **805***a*-**1**, **805***a*-**2**, **805***a*-**3**, and **805***a*-**4** with corresponding hashes **805***b*-**1**, **805***b*-**2**, **805***b*-**3**, and **805***b*-**4**. Because hashes **805***a*-**3** and **805***b*-**3** are not identical, the facility evaluates the next hashing level (not shown) to determine the metadata differences of the item of data represented by the entry from which **805***a*-**3** and **805***b*-**3** were generated.

To identify the metadata differences associated with an item of data (e.g., an inode), the facility compares corresponding hashes **800** of each attribute of the entry associated with the identified item of data. That is, once the entries are identified, the same approach is applied to the changed entries to identify the individual attributes that have changed. The hash comparison introduced herein produces a quick determination of whether the metadata of the corresponding entries (e.g., inodes) are different and allows a more time-consuming attribute-by-attribute comparison to be avoided if they are the same. That is, in some embodiments, it is sufficient to identify the attributes differences without comparing the metadata for the attributes.

After identifying the specific attribute differences, the facility stores certain information from the two inodes and information about the differences. For example, this information may be provided in a table, and include a separate entry for each pair of corresponding inodes that are found to be different between the two baselines. Each entry (e.g., for each changed item of data) may include, for example:

- inode number of the item of data;
- timestamp to indicate the date/time of the relative create/modify;
- size of the item of data for both baselines;
- link count of the item of data for both baselines;
- number of data blocks in the item of data for both baselines;
- permissions of the item of data for both baselines;
- user ID to indicate the owner of the item of data for both baselines;
- group ID to indicate the group owner of the item of data for both baselines (A user belongs to at least one group. When a user creates an item, their initial group is used as the group ID for that item as well as their user ID);
- root inode number to identify the root inode attached to an item of data, for both baselines (This parameter is specific to Windows based file systems. A stream can hold information such as security information or "data." On a Unix based system, the root inode number for most files will be 0, because streams are not associated with Unix-based files);
- xinode number to identify the inode that contains the access control list (ACL) for a item of data, for both baselines (item of data may share xinodes if their content is the same. On a Unix based system, the xinode number for most files will be 0 for the same reasons as the root inode number);
- a set of bit flags, which can be used for any of various purposes (For example, one or more of the bit flags can be used to indicate the types of changes detected in the inode (e.g., a "ink count changed" bit flag, a "block count changed" bit flag, etc.). The manner in which the specific types of changes are identified is unimportant; any conventional technique for doing so can be used); and
- the number of common entries of the baselines or, conversely, the number of entries which changed between the baselines (Note that the number of common entries are applicable only for modified items, not for deleted or added items of data).

In certain embodiments of the invention, the facility stores difference information describing two or more baselines in two or more distinct files. For example, there may be file to record all deletions and another file to record all other types of differences (i.e., additions, modifies, renames). This approach is desirable if, for example, inodes can be reused. For example, assume a file "foo1" with inode number **100** is deleted between time T**1** and time T**2**, and another file "foo2" is subsequently created between time T**1** and T**2** and assigned inode number **100**. Without the use of two separate files, as just noted, it would be difficult if not impossible to distinguish this deletion and creation from a modify.

As described herein, the facility generates a report or catalog **450**, i.e., a log file in human readable form. The catalog **450** includes the locations of the items of data for which differences were identified. The "location" of an item of data is the item's complete pathname, i.e., including the item name and the names of any directories and subdirectories in which the item is located, from the root of the volume to the item itself, in human-readable form.

The locations can be determined simply by "walking" the file system trees starting from the root nodes, and recording the various directories and subdirectories along the path to each changed item. A technique for quickly and efficiently walking a hierarchical dataset to identify locations of changed files and directories, which is suitable for this purpose, is described in co-pending U.S. patent application Ser. No. 10/954,381 of S. Manley et al., filed on the Sep. 29, 2004 and entitled, "Method and Apparatus for Generating User-Level Difference Information About Two Data Sets," ("the Manley technique"), which is incorporated herein by reference.

For each item of data for which a difference was identified between the baselines, the location of the item is determined and recorded in the catalog **450**, along with information identifying (in human-readable form) the type(s) of difference(s) identified. The catalog **450** may have any desired format, such as a table of item names with their associated location and change information, a list, etc. For example, a typical entry in the catalog **450** might appears as follows:

Item "English_bulldogs" modified at blocks **4** and **16**; location=/vol6/pushed_nose_dogs/bulldogs/English_bulldogs

Thus, a facility for generating human-readable difference information about two datasets irrespective of the file system implemented by the storage server has been described. Note that references throughout this specification to "one embodiment" or "an embodiment" means that a particular feature, structure or characteristic described in connection with the embodiment is included in at least one embodiment of the present invention. Therefore, it is emphasized and should be appreciated that two or more references to "an embodiment" or "one embodiment" or "an alternative embodiment" in various portions of this specification are not necessarily all referring to the same embodiment. Furthermore, the particular features, structures or characteristics being referred to may be combined as suitable in one or more embodiments of the invention, as will be recognized by those of ordinary skill in the art.

Although the present invention has been described with reference to specific exemplary embodiments, it will be recognized that the invention is not limited to the embodiments described, but can be practiced with modification and alteration within the spirit and scope of the appended claims. Accordingly, the specification and drawings are to be regarded in an illustrative sense rather than a restrictive sense.

We claim:

1. A method of identifying differences between a first dataset and a second dataset, the method comprising:

comparing, by a data storage system, a first hierarchical tree of metadata hashes representing the first dataset and a second hierarchical tree of metadata hashes representing a second dataset, the first and second datasets each including a plurality of data blocks of the data storage system, the first and second hierarchical trees each including a plurality of hierarchical hash values corresponding to metadata describing the plurality of data blocks included in the first and second datasets, the metadata including an inode indicator associated with the plurality of data blocks, to identify changes between the first and second datasets by progressively comparing the hierarchical hash values of the first and second hierarchical trees without comparing the metadata associated with the data blocks included in the first and second datasets, wherein:

the first and second hierarchical trees each include a base layer of hashes and one or more upper levels of hashes, each upper level hash being a hash value of a corresponding subset of hashes from an immediately lower layer of hashes,

each base layer of hashes includes a plurality of data-block level hashes, each data-block level hash corresponding to metadata associated with a given data block of the plurality of data blocks,

each data-block level hash is a hash value of a plurality of attribute hashes, each of the plurality of attribute hashes corresponding to a hash value of a different attribute associated with a corresponding inode indicator, the different attributes including access attributes associated with a data block corresponding to the inode indicator; and

generating, by the data storage system, a catalog indicating changes in metadata between the first and second datasets.

2. The method of claim **1** further comprising determining a location of at least one item of data in the first and second datasets for which a metadata change has been indicated; and

including the location of the at least one item of data in the catalog.

3. The method of claim **1** wherein the first and second datasets each comprise a plurality of structured items of data.

4. The method of claim **1** wherein the first and second datasets are baselines of a file system at different points in time.

5. An apparatus comprising:

a storage adapter through which to access a nonvolatile mass storage subsystem; and

a processor coupled to the storage adapter;

a comparison unit to compare a first hierarchical tree of metadata hashes representing a first logical data container and a second hierarchical tree of metadata hashes representing a second logical data container, the first and second logical data containers each referencing a plurality of data blocks in the nonvolatile mass storage subsystem, the first and second hierarchical trees each including a plurality of hierarchical hash values corresponding to metadata describing the plurality of data blocks referenced by the first and second logical data containers, the metadata including an inode indicator associated with the plurality of data blocks, to identify changes in metadata of the first and second logical data containers by progressively comparing the hierarchical hash values of the first and second hierarchical trees without comparing the metadata associated with the data blocks referenced by the first and second logical data containers, wherein:

the first and second hierarchical trees each include a base layer of hashes and one or more upper levels of hashes, each upper level hash being a hash value of a corresponding subset of hashes from an immediately lower layer of hashes,

each base layer of hashes includes a plurality of data-block level hashes, each data-block level hash corresponding to metadata associated with a given data block of the plurality of data blocks,

each data-block level hash is a hash value of a plurality of attribute hashes, each of the plurality of attribute hashes corresponding to a hash value of a different attribute associated with a corresponding inode indicator, the different attributes including access attributes associated with a data block corresponding to the inode indicator; and

a catalog unit to generate a catalog of changes between the first and second logical data containers, the catalog indicating changes in metadata between the first and second metadata containers.

6. The apparatus of claim **5** further comprising a monitoring unit to monitor transaction requests corresponding to items of data included in the first and second logical data containers and, based on a number of transaction requests, determine a level of hashing.

7. The apparatus of claim **6** wherein the monitored transaction requests are requests to store items of data.

8. The apparatus of claim **6** further comprising a hash-generating unit to generate the first and second hierarchical hashes based on the hashing level determined.

9. A processing system comprising:

a processor; and

a storage medium encoded with instructions that, when executed by the processor, cause the processing system to:

compare a first hierarchical tree of metadata hashes representing a first dataset and a second hierarchical tree of metadata hashes representing a second dataset, the first and second datasets each including a plurality of data blocks of the data storage system, the first and second hierarchical trees each including a plurality of hierarchical hash values corresponding to metadata describing the plurality of data blocks included in the first and second datasets, the metadata including an inode indicator associated with the plurality of data blocks, wherein:

the first and second hierarchical trees each include a base layer of hashes and one or more upper levels of hashes, each upper level hash being a hash value of a corresponding subset of hashes from an immediately lower layer of hashes,

each base layer of hashes includes a plurality of data-block level hashes, each data-block level hash corresponding to metadata associated with a given data block of the plurality of data blocks,

each data-block level hash is a hash value of a plurality of attribute hashes, each of the plurality of attribute hashes corresponding to a hash value of a different attribute associated with a corresponding inode indicator;

identify changes between the first and second datasets by progressively comparing the hierarchical hash values of the first and second hierarchical trees without comparing the metadata associated with the data blocks of the first and second datasets; and

generate a catalog indicating changes in metadata between the first and second datasets.

10. The processing system of claim **9** wherein the processing system comprises a storage server.

11. The processing system of claim **10** wherein the storage server generates the first and second hierarchical hashes.

12. The processing system of claim **9** wherein the first and second hierarchical hashes are acquired on a periodic basis.

13. The processing system of claim **9** wherein progressively comparing the hierarchical hash values further comprises:

determining that the metadata of the first dataset from which the hash value was generated is the same as the metadata from the second dataset from which the corresponding hash value was generated when a hash value of the first hierarchical hash is the same as a corresponding hash value of the second hierarchical hash.

14. The processing system of claim **13** wherein progressively comparing the hierarchical hash values further comprises:

comparing a next hash value of the first hierarchical hash with a corresponding next hash value of the second hierarchical hash when the hash value of the first hierarchical hash is different from the corresponding hash value of the second hierarchical hash; and

determining that the metadata of the first dataset from which the hash value was generated is different from the metadata from the second dataset from which the corresponding hash value was generated when the hash value of the first hierarchical hash is different from the corresponding hash value of the second hierarchical hash and there are no next hash values.

15. The processing system of claim **9** further comprising:

a storage interface to communicate with an array of storage devices to retrieve data from or store data to the array of storage devices; and

a network interface to communicate with at least one client over a network; the processing system being configured process transaction requests from the clients related to data stored in the array of storage devices.

16. The processing system of claim **9** wherein the first and second datasets are baselines of volume of data at difference points in time.

17. The processing system of claim **16** wherein the volume of data comprises unstructured data.

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